Foundation Design and Construction

2009 Construction Training

Western Federal Lands Highway Division

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Geotechnical Engineer

Session Outline

- Foundation Selection
  - Surface and subsurface conditions
  - Pros and cons
- Design
- Construction
- Case History

Foundation Selection

Site Surface and Subsurface Conditions

- Topography
- Vegetation
- Utilities
- Rivers
- Railroad tracks
- Roads/highways
- Landslides, debris flows, slumps, creeps, etc.
- Subsurface soil types
- Depth to bedrock or hard stratum
- Location of water table
- Wetlands
- Historical sites

Subsurface Conditions

- Soil profile
- Water table
- Depth to bedrock/hard stratum
- Compressible soils – drag loads
- Site seismicity
- Nearby faults

Spread Footings
(within 10 feet of existing grade)

- Pros:
  - Usually most cost effective for shallow depths
  - Easy to construct
  - No specialty contractor required
  - Subgrade can be easily inspected before pouring concrete
- Cons:
  - Require large excavation – size increases with depth
  - Constructability below water table and in water ways
  - Susceptible to scour

Driven Piles

(when spread footings aren't feasible)

- Pros
  - Most contractors can perform the work
  - Transmit loads deep
  - Inexpensive to dynamic test (PDA and CAPWAP)
  - Closed-end pipe & monotube piles can be inspected for damage after driving
- Cons
  - Potential to buckle during deep scour event
  - May not be feasible to drive below deep scour elevations
  - Difficult to install in some conditions – may be damaged in cobbles and boulders
  - Design is difficult when there is no bedrock or hard stratum - floating piles – potential for costly change orders
  - H-piles cannot be inspected after driving

Hmmm…

D'oh!

Drilled Shafts

(when spread footings aren't feasible)

- Pros
  - Transmit loads deep
  - High axial and lateral capacities
  - Minimal footprint – can be constructed in river without cofferdam
- Cons
  - Relatively expensive
  - Requires specialty contractor
  - Costly to verify loads
  - Can be difficult to install in bouldery deposits

Piles v. Shafts

(when spread footings aren’t feasible)

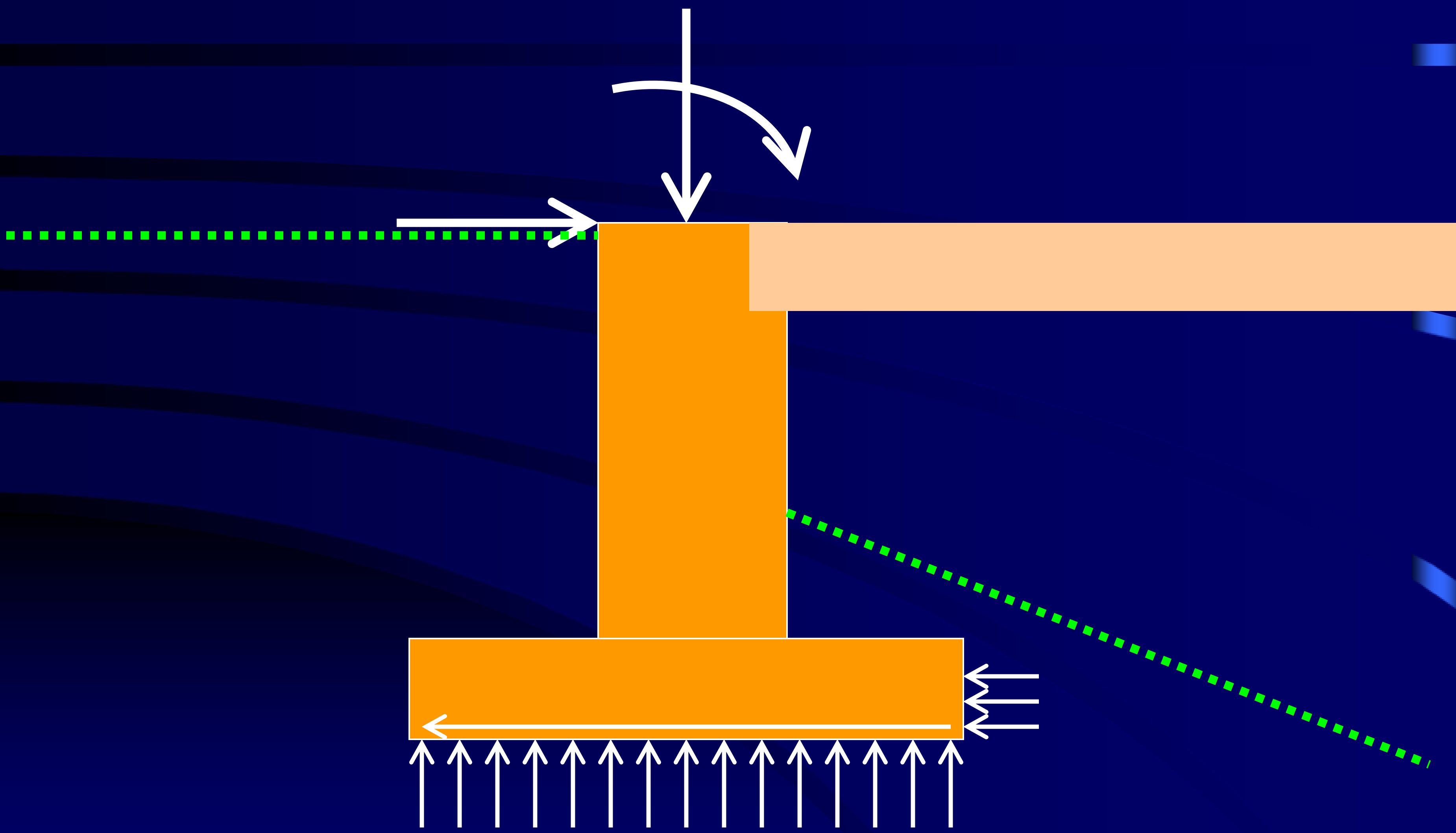
- Piles
  - Soft stratum overlying bedrock
  - Scour is not significant
  - Lateral loads are relatively small
- Drilled shafts
  - Axial and lateral loads are significant
  - Deep scour

Design

Design – Sizing Foundations

- Axial Capacity
- Lateral Capacity
- Settlement

Spread Footings



Spread Footings

$$q_u = cN_cF_{cs}F_{cd}F_{ci} + qN_qF_{qs}F_{qd}F_{qi} + 1/2\gamma BN_\gamma F_{\gamma s}F_{\gamma d}F_{\gamma i}$$

c = cohesion

q = effective stress at bottom of footing elevation

γ = unit weight of soil

B = width of footing

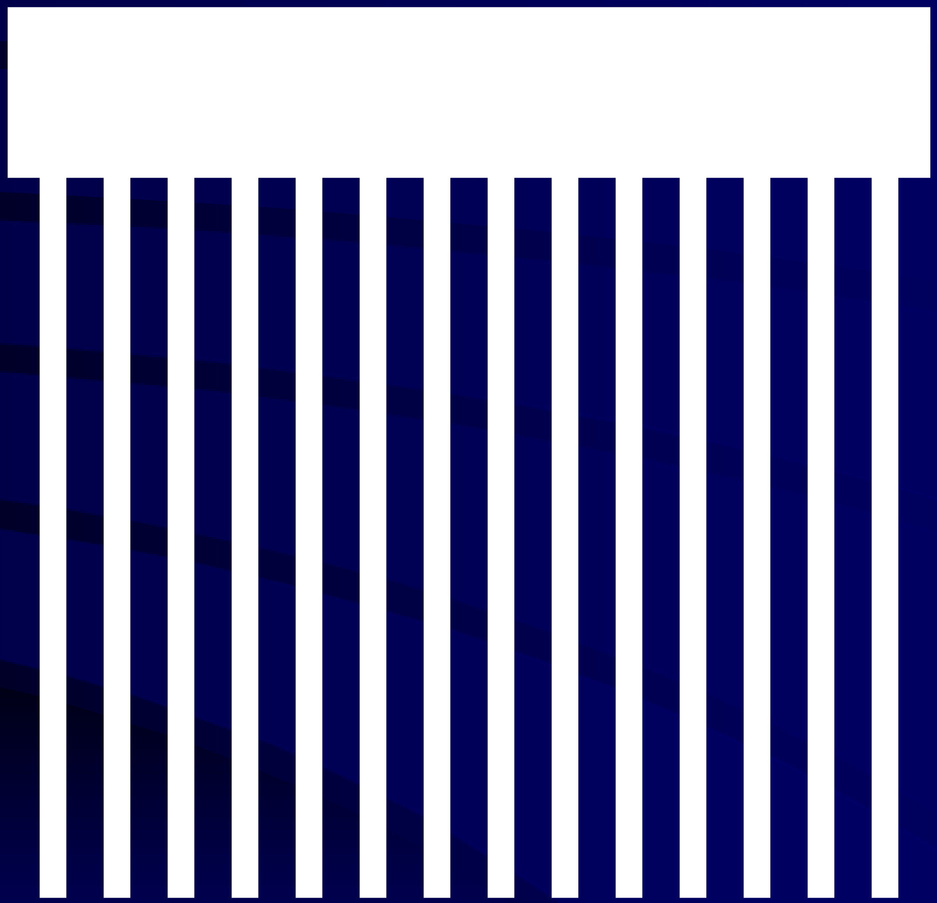
F_{cs}, F_{qs}, $F_{\gamma s}$ = shape factors

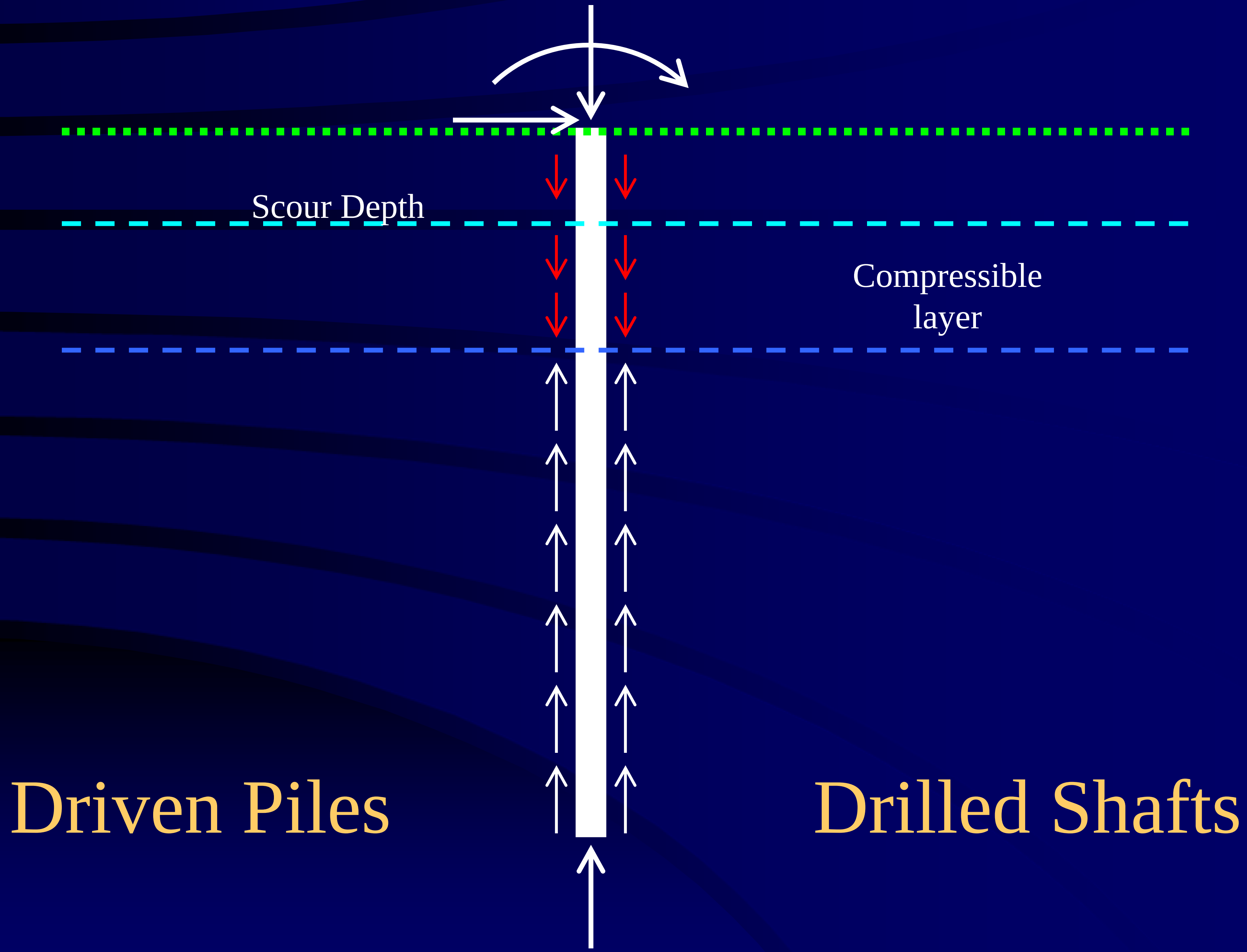
F_{cd}, F_{qd}, $F_{\gamma d}$ = depth factors

F_{ci}, F_{qi}, $F_{\gamma i}$ = load inclination factors

N_c, N_q, N_γ = bearing capacity factors

Driven Piles




Scour Depth
Compressible layer
Driven Piles
Drilled Shafts

Driven Piles and Drilled Shafts

$$Q_u = (\pi DL)q_s + (\pi D^2/4)q_p$$

D = diameter

L = length

q_s = skin resistance

q_p = point resistance

Construction

Spread Footings

- Keep water out of excavation at all times
- Have a Geotech look at the subgrade conditions before pouring concrete

Driven Piles

ICE I -80

I-80V2		
Ram Weight	17700	lbs
Maximum Geometric Stroke	13.5	ft
Energy @ Max Stroke	238950	ft-lbs
Rated Continuous Stroke	12	ft
Energy @ Rated Stroke	212400	ft-lbs
Blow Rate	33-53	bpm
Weight w/ Box-lead Guides	41920	lbs
Typical Helmet Weight	5200	lbs
Typical Operating Weight	47120	lbs

Driven Piles

- Keep driving logs for <u>all</u> piles
- Understand the basis for the design – required minimum tip elevation and required ultimate capacity
- <u>Never</u> use ENR formula

Drive to specified tip elevation, minimum capacity, or both?

Sometimes axial capacity is not relevant…

Pile Specifications – Equipment Submittal

- Equipment Submittal – includes wave equation analysis - forward to Geotech for review
- Wave equation analysis must show that the proposed hammer system can drive the piles to the required ultimate capacity at between 3 and 10 blows/inch

Pile Specifications – Driven Pile Capacity

- Test piles
- Wave equation – GRL WEAP
- Dynamic formula

$$R_u = 1.6\sqrt{eE}\,\log_{10}(10N) - 100$$

- Load Tests
  - PDA – Pile Dynamic Analyzer & CAPWAP – CAse Pile Wave Analysis Program
  - Static Load Test

Drilled Shafts

Drilled Shafts

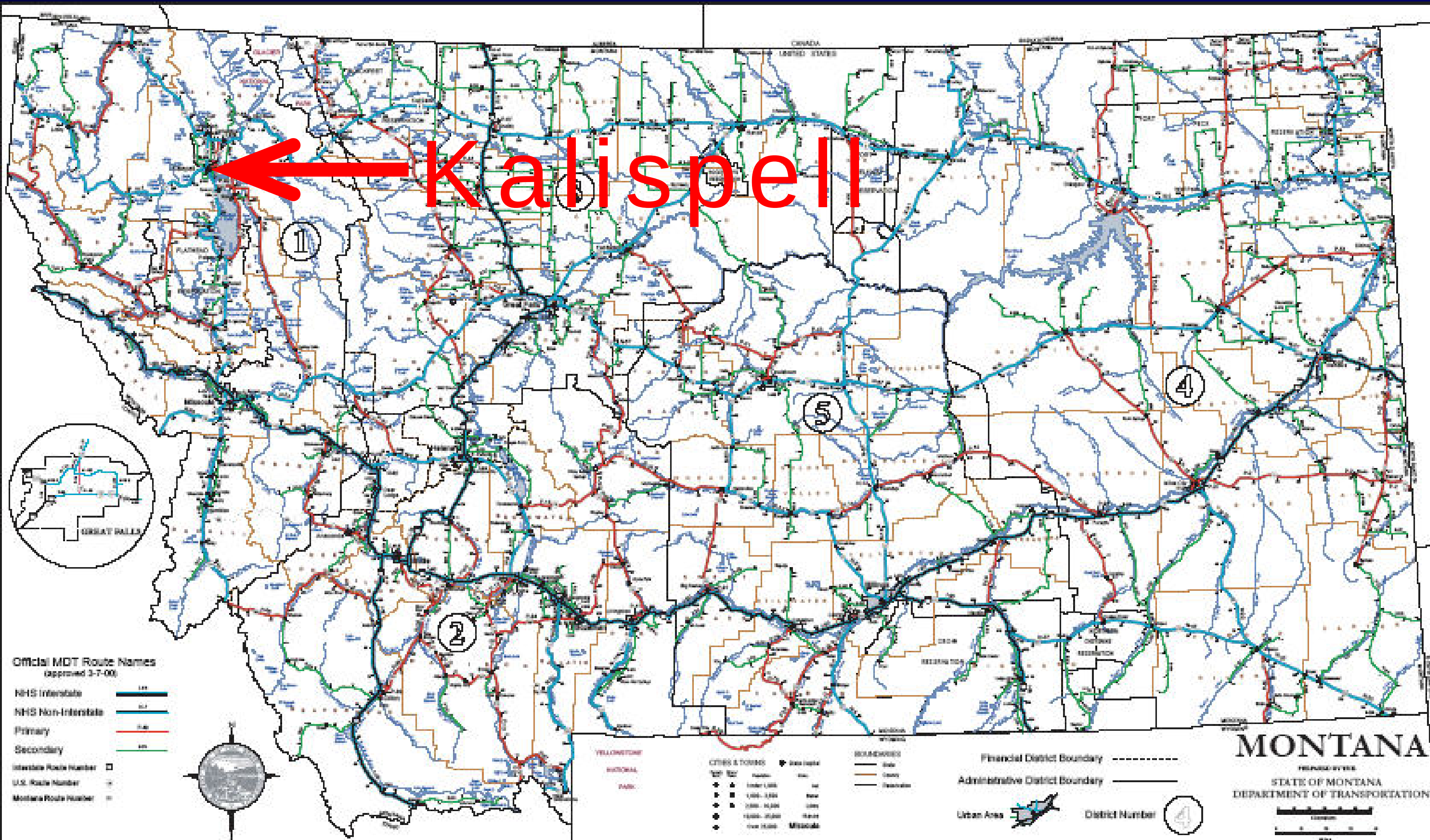
- Keep a log of the excavation – Geotech
- Clean out shaft after completion
- Installation methods
  - Dry Method (above water table and cohesive soils)
  - Wet Method (below water table and cohesionless soils)
    - Slurry
    - Casing

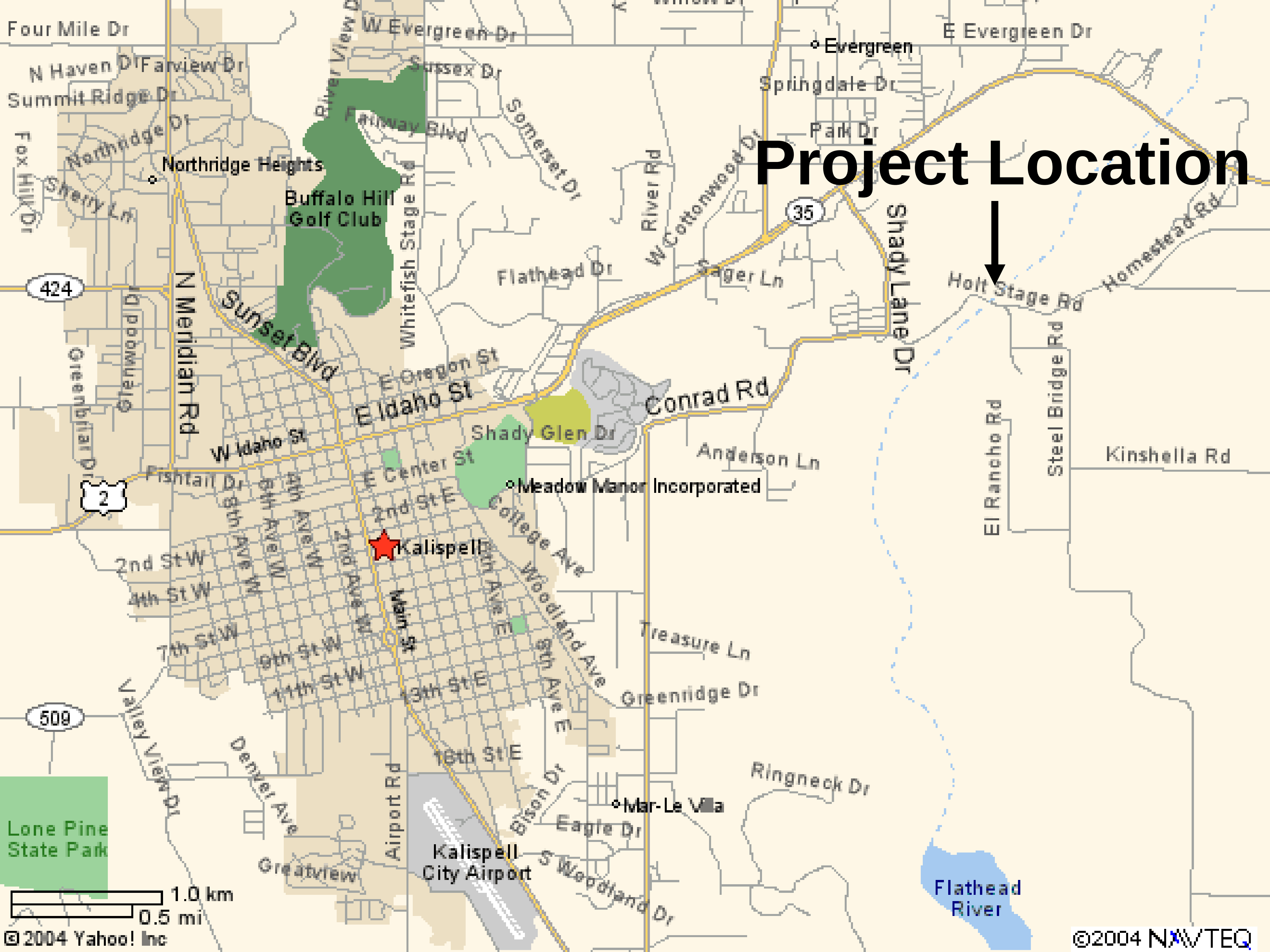
Drilled Shaft Specifications

- Installation Plan Submittal - forward to Geotech for review
- Installation method – wet or dry
- Inspect shaft – test hole, SPT, or visual
- Concrete pour
  - Maintain 5 ft head of concrete above water when using casing
  - Free fall pour only allowed in dry holes
  - Use tremie or pump in wet holes – keep end of tremie/hose below level of concrete
- Perform CSL (cross-hole sonic log) testing

Case History

Flathead River




Project Location
Four Mile Dr
N Haven Dr
Fairview Dr
Summit Ridge Dr
Northridge Dr
Northridge Heights
Sherry Ln
Fox Hill Dr
Buffalo Hill Golf Club
River View Dr
W Evergreen Dr
Sussex Dr
Fairway Blvd
Somerset Dr
Whitefish Stage Rd
Flathead Dr
River Rd
W Cottonwood Dr
Evergreen
E Evergreen Dr
Springdale Dr
Park Dr
35
Sager Ln
Shady Lane Dr
Holt Stage Rd
Homestead Rd
424
Glenwood Dr
Greenbriar Dr
N Meridian Rd
Sunset Blvd
E Oregon St
E Idaho St
Conrad Rd
Shady Glen Dr
W Idaho St
Anderson Ln
El Rancho Rd
Steel Bridge Rd
Kinshella Rd
Fishtail Dr
2
E Center St
Meadow Manor Incorporated
2nd St E
College Ave
Kalispell
2nd St W
4th St W
7th St W
9th St W
11th St W
13th St E
Main St
Woodland Ave
Treasure Ln
Greenridge Dr
509
Valley View Dr
Denver Ave
16th St E
Ringneck Dr
Bison Dr
Mar-Le Villa
Eagle Dr
Airport Rd
Kalispell City Airport
S Woodland Dr
Lone Pine State Park
Greatview
Flathead River
1.0 km
0.5 mi
©2004 Yahoo! Inc
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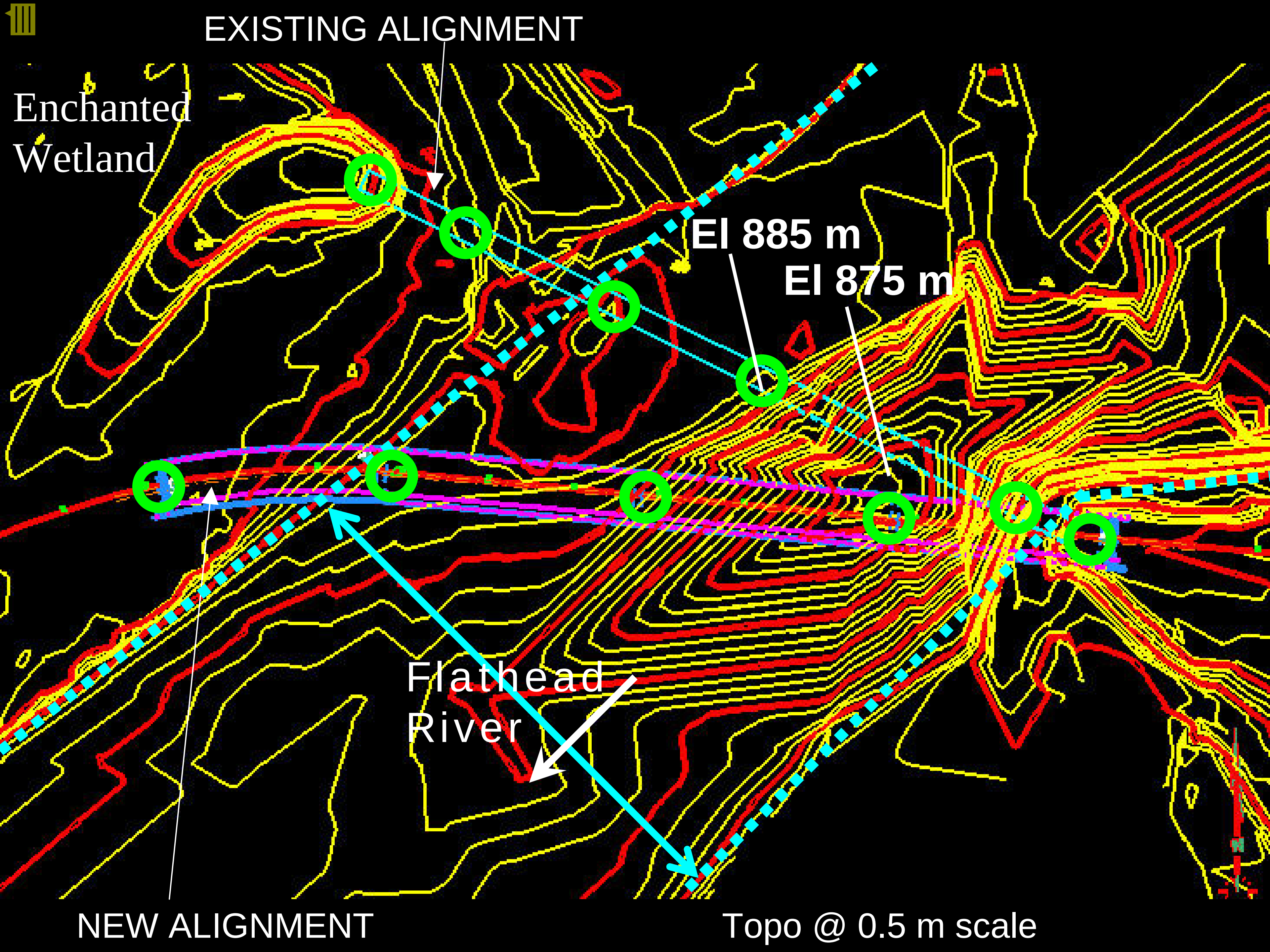
4. 9. 2003

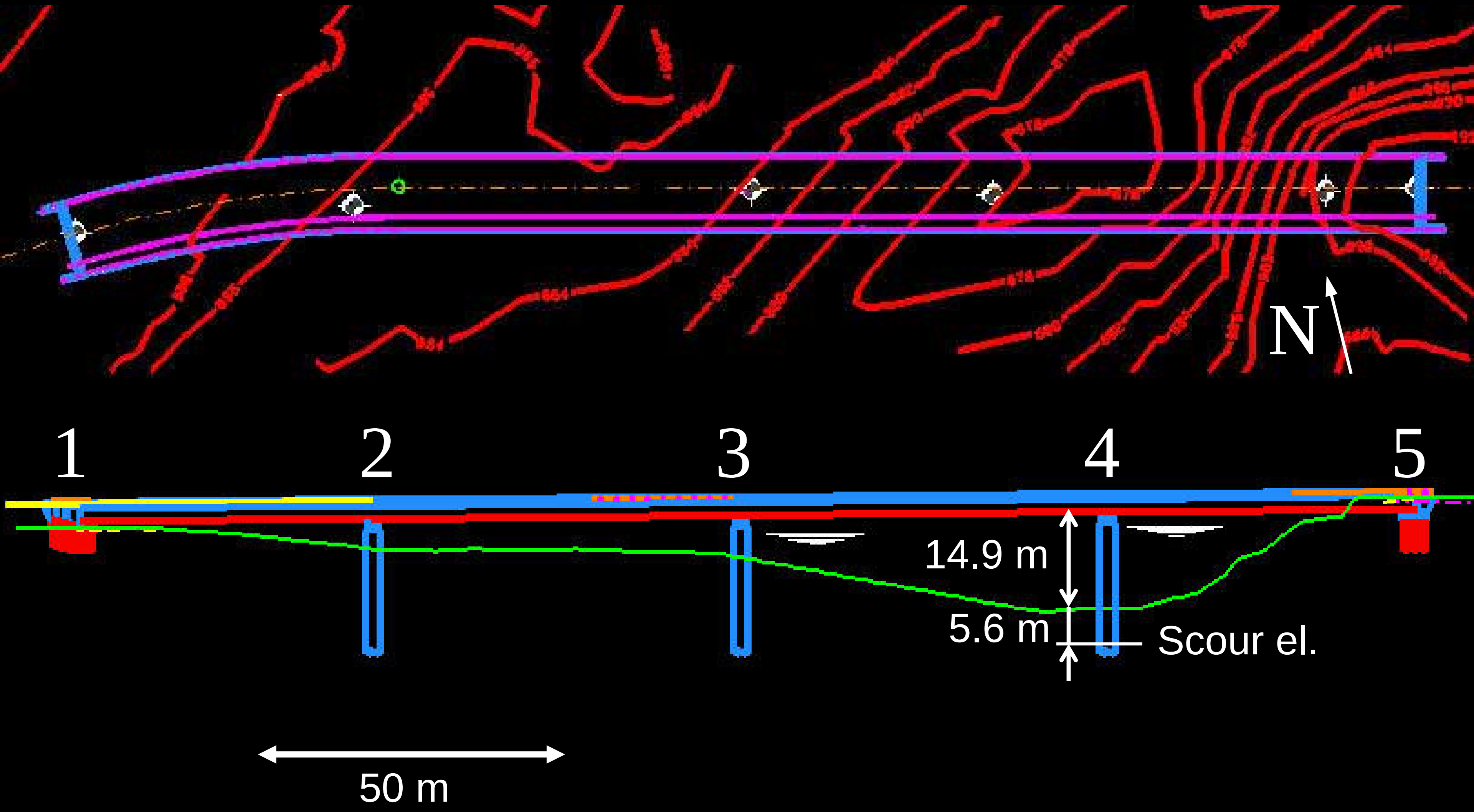
The Old Bridge Had Some Issues

Existing Bridge

- Constructed in 1894
- Total length = 184 m (600 ft)
- Five timber approach spans
- Three steel through-truss main spans
  - 2 @ 43 m (140 ft)
  - 1 @ 77 m (250 ft)
- Expansion bearings no longer function
- Severely deteriorated timber deck and abutments
- Closed for safety reasons in June 2005


EXISTING ALIGNMENT
Enchanted Wetland
El 885 m
El 875 m
Flathead River
NEW ALIGNMENT
Topo @ 0.5 m scale

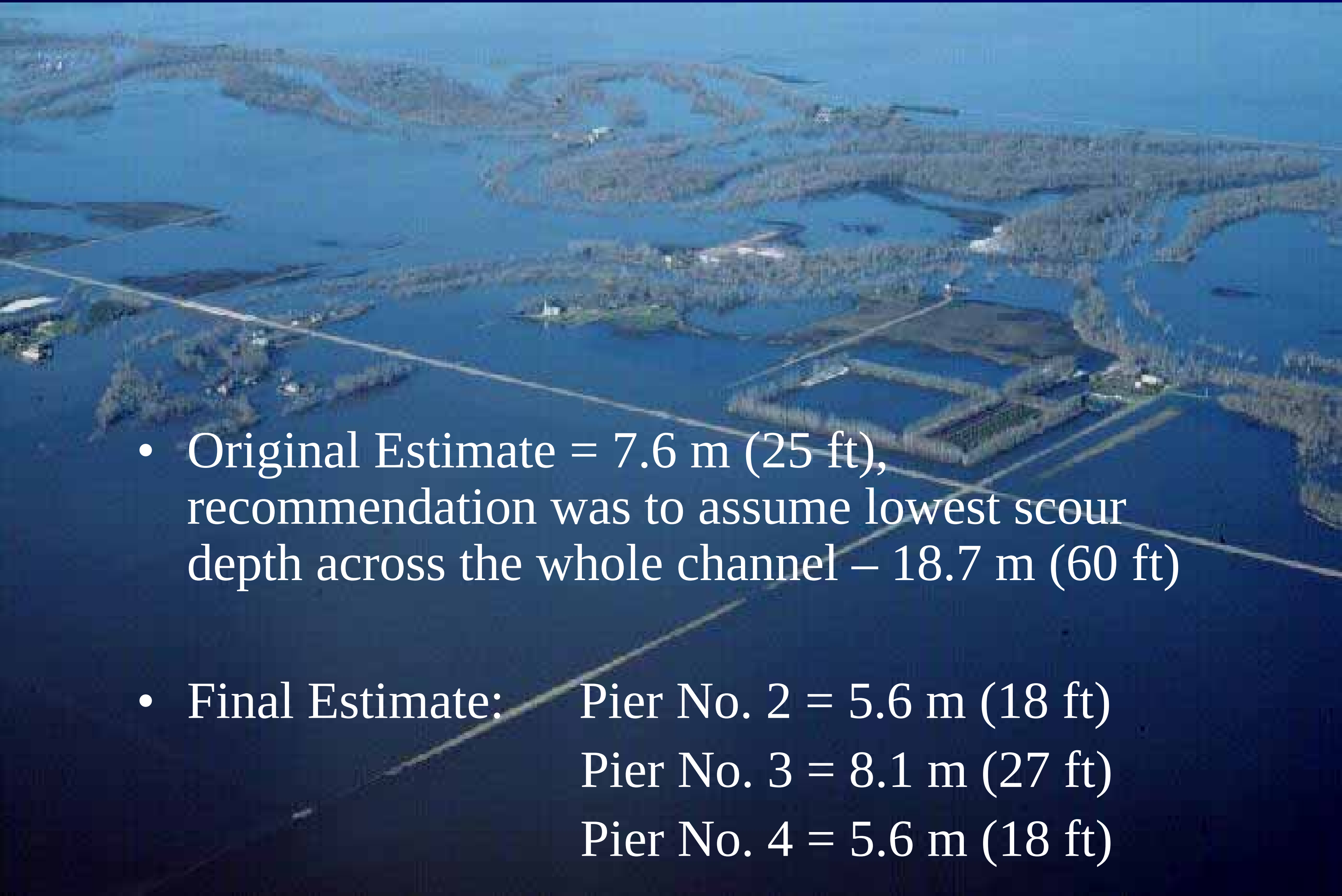
Plan & Profile



Design Loads for Drilled Shafts

- Axial Load: 10,695 kN (1200 ton)
- Lateral Loads:
  - Pier No. 2 = 1711 kN (192 ton)
  - Pier No. 3 = 1744 kN (196 ton)
  - Pier No. 4 = 1802 kN (203 ton)

Scour



- Original Estimate = 7.6 m (25 ft), recommendation was to assume lowest scour depth across the whole channel – 18.7 m (60 ft)

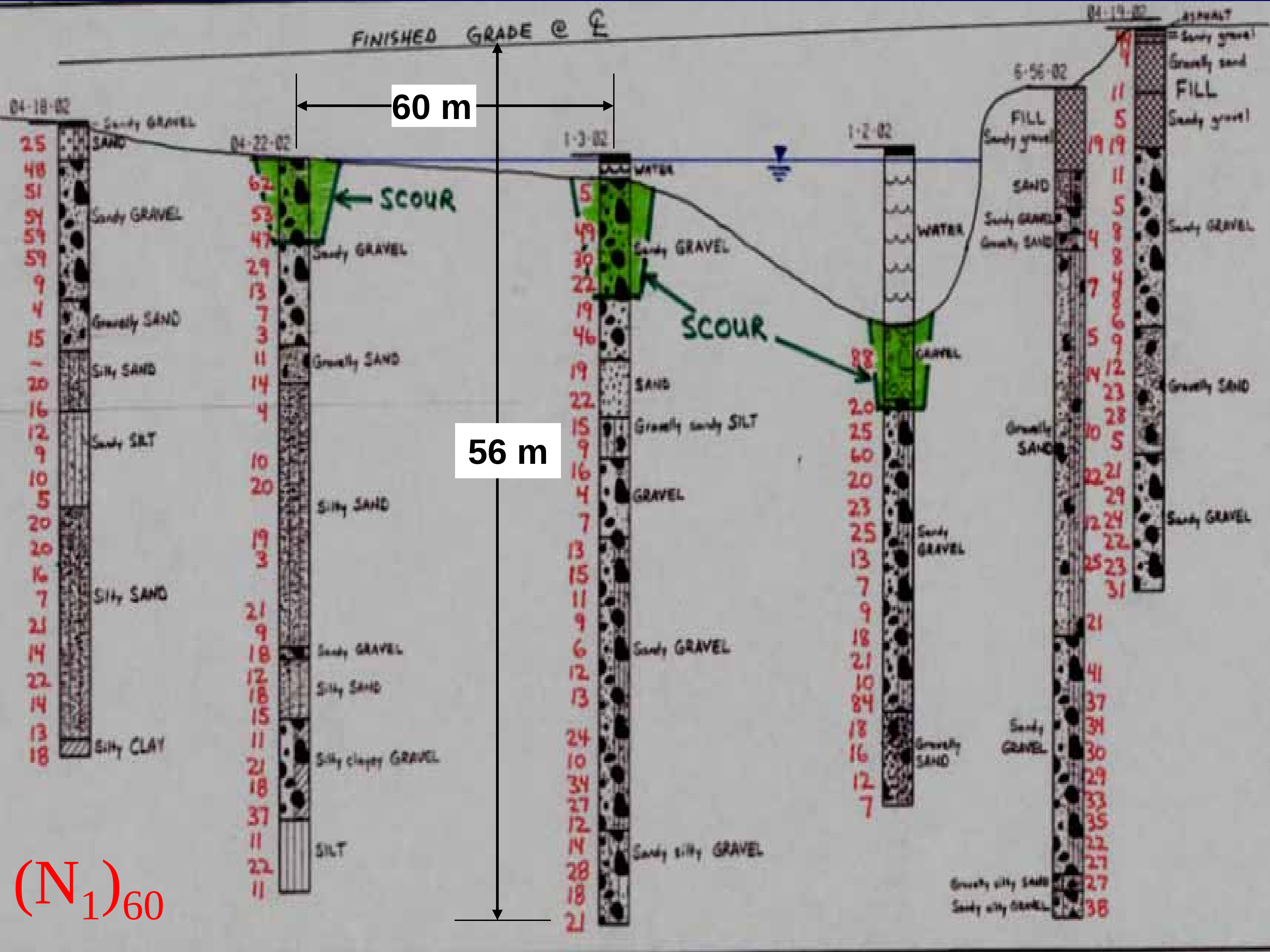
- Final Estimate: Pier No. 2 = 5.6 m (18 ft)
  Pier No. 3 = 8.1 m (27 ft)
  Pier No. 4 = 5.6 m (18 ft)

Subsurface Investigation

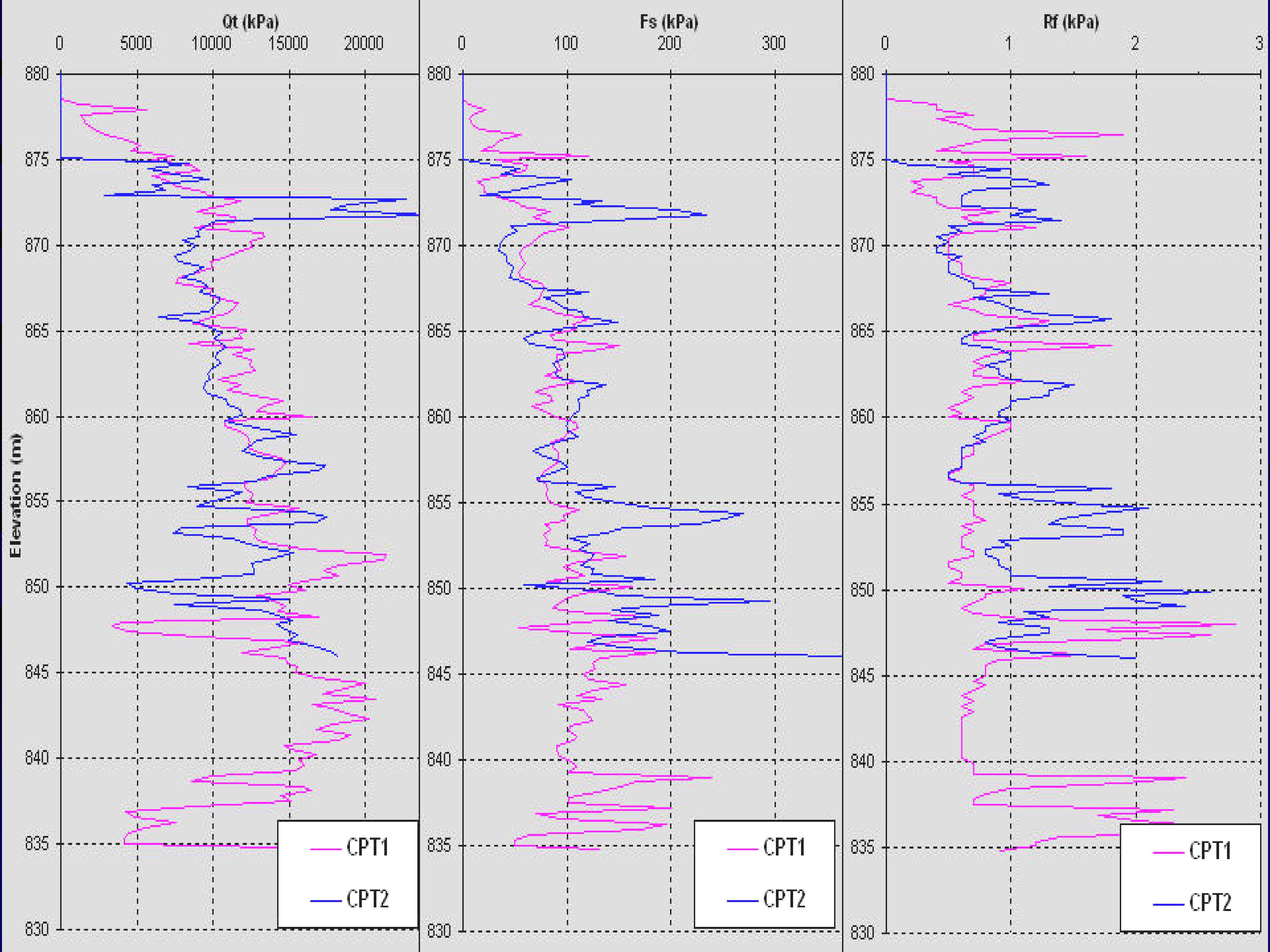
Area Geology

- Alluvium consisting mostly of valley fill (Holocene deposits)
  - Clay, silt, sand, gravel and cobbles, occasional boulders
- Depth to bedrock is about 730 m (2400 ft)

(Smith, 2004)

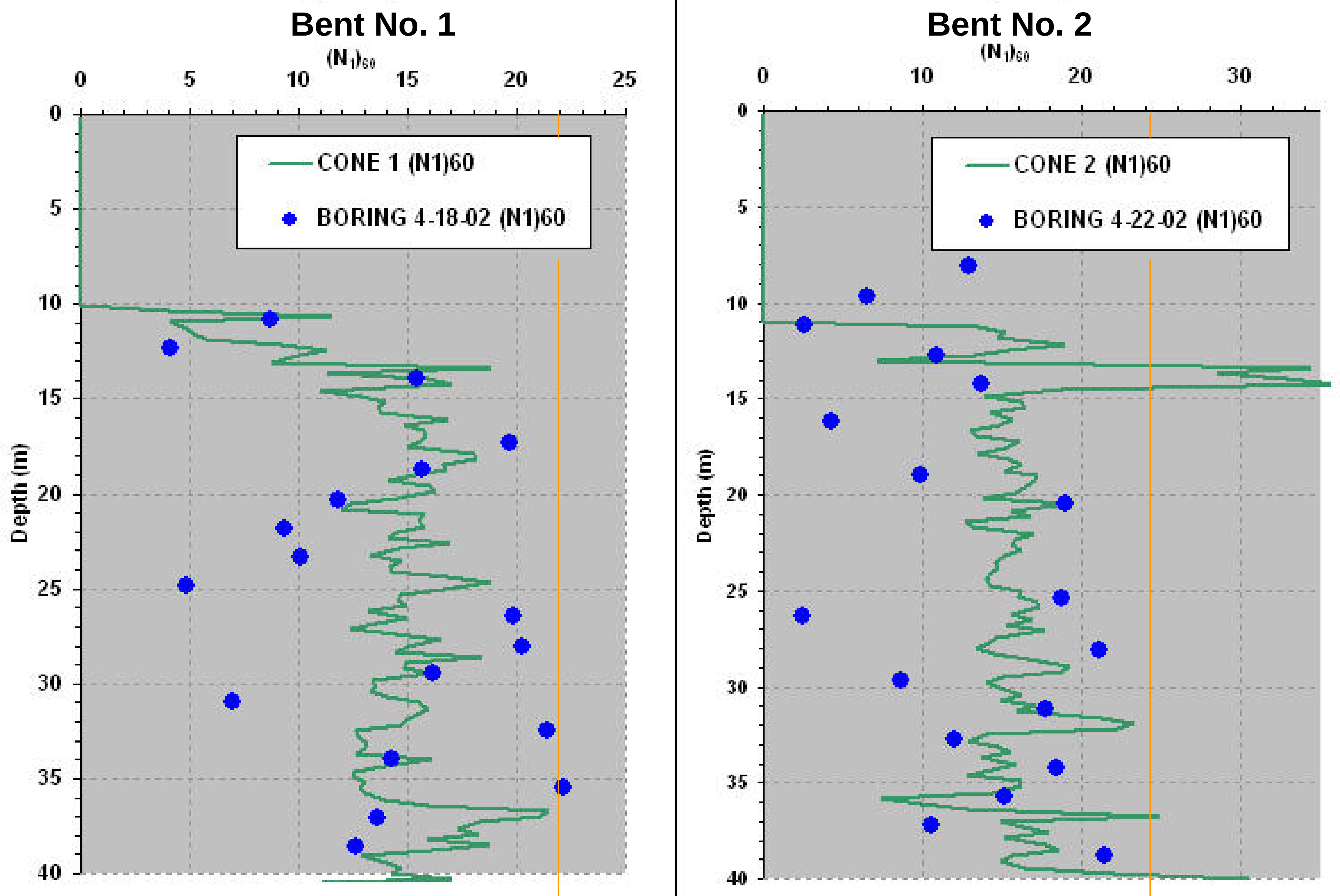


FINISHED GRADE @ ℄
60 m
56 m
SCOUR
SCOUR
04-18-02
04-22-02
1-3-02
1-2-02
6-56-02
04-19-02
Sandy GRAVEL
SAND
Gravelly SAND
Silty SAND
Sandy SILT
Silty CLAY
Silty clayey GRAVEL
SILT
WATER
Gravelly sandy SILT
GRAVEL
Sandy silty GRAVEL
Gravelly SAND
FILL
Sandy gravel
Gravelly sand
ASPHALT
Gravelly silty SAND
Sandy silty GRAVEL
$(N_1)_{60}$



Qt (kPa)
0
5000
10000
15000
20000
Fs (kPa)
0
100
200
300
Rf (kPa)
0
1
2
3
880
875
870
865
860
855
850
845
840
835
830
Elevation (m)
CPT1
CPT2

Comparison between CPT and SPT – $(N_1)_{60}$

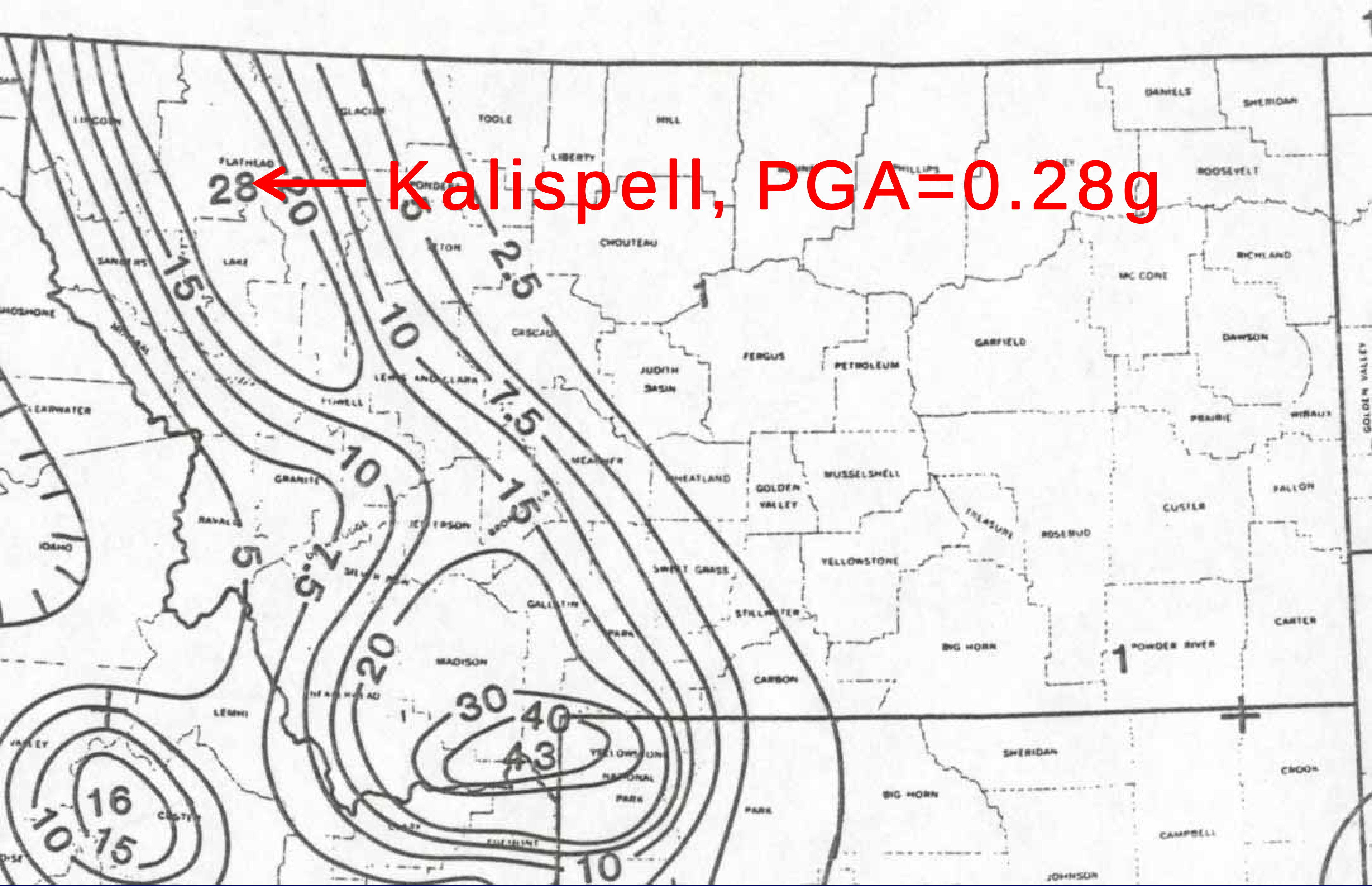


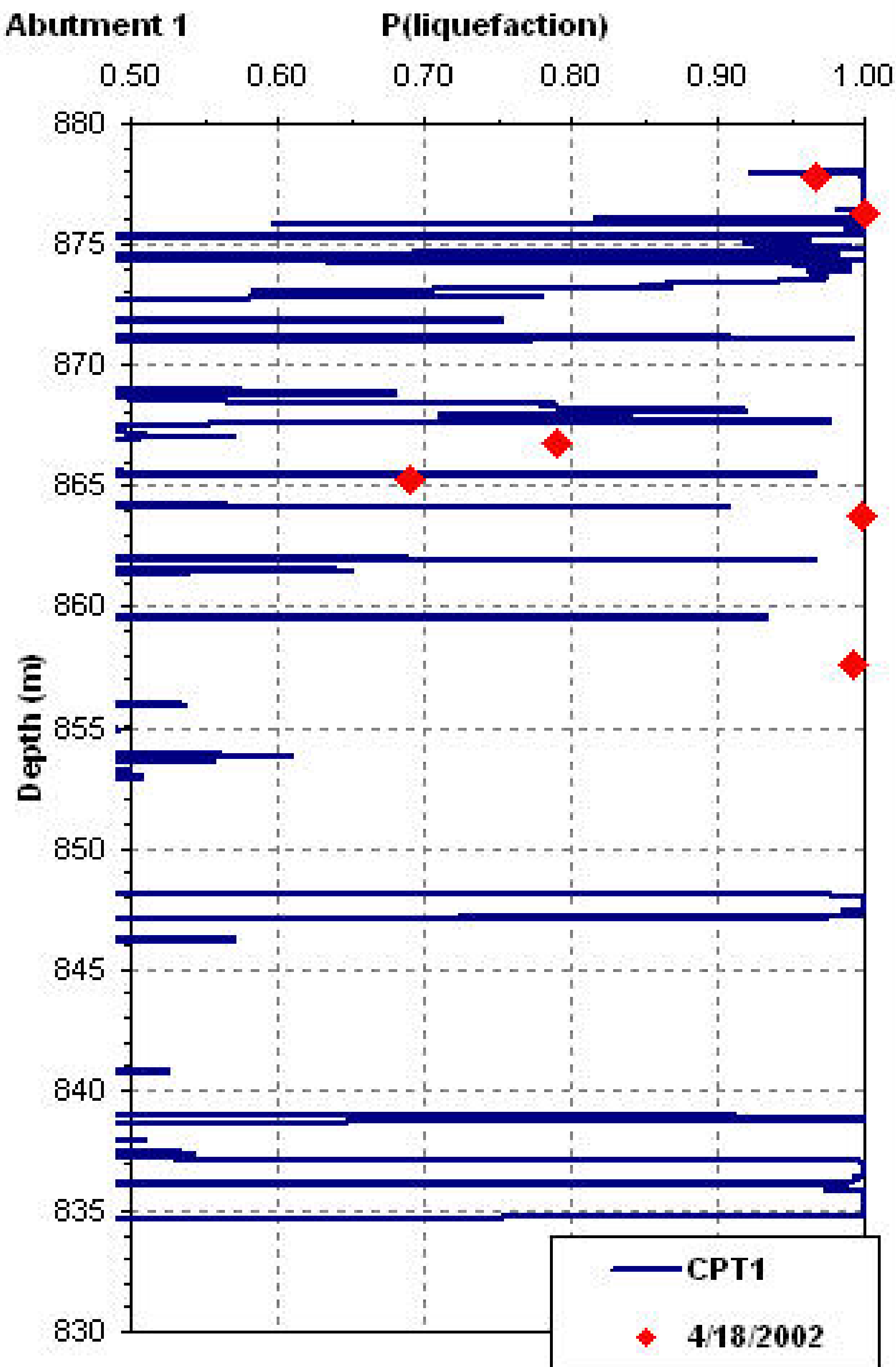
Summary of Site Investigation

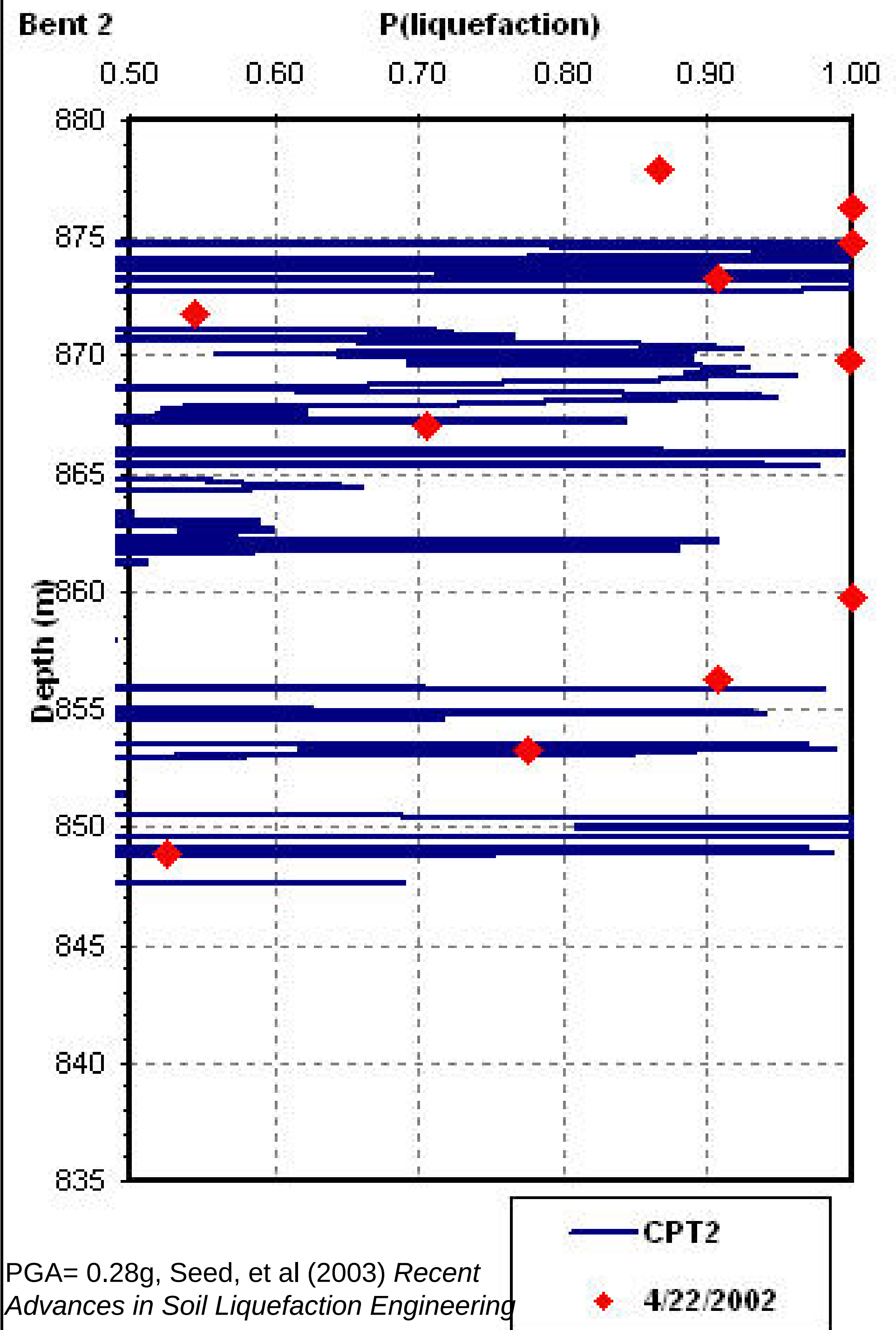
- Typical alluvial environment – variable stratigraphy
- Deep cohesionless deposits with no dense bearing stratum encountered
- Decent correlation between SPT and CPTu
- Fines are nonplastic

What Else…?

AASHTO Map of Horizontal Acceleration



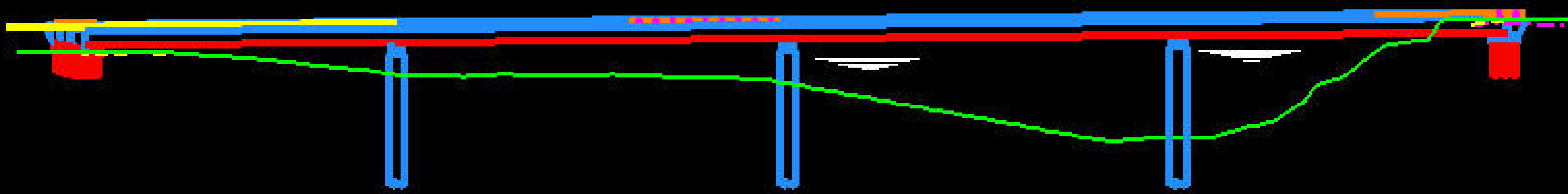




PGA= 0.28g, Seed, et al (2003) *Recent Advances in Soil Liquefaction Engineering*

Design Considerations

- Bridge alignment and layout
- Lack of dense/hard bearing stratum
- Potential for liquefaction
  - Loss of pile capacity
  - Drag loads
  - Slope stability
- Piers (especially Pier No. 4)
  - Deep water
  - Significant scour
  - Large axial and lateral loads



Design Considerations, cont’d

- End bents – driven piles
- Constructability of Pier No. 4
  - Deep water with fast current
  - Will installation and removal of temporary casing be feasible? What will capacity be with full length permanent casing?
  - Contractor qualifications
- Cost $,$$$,$$$

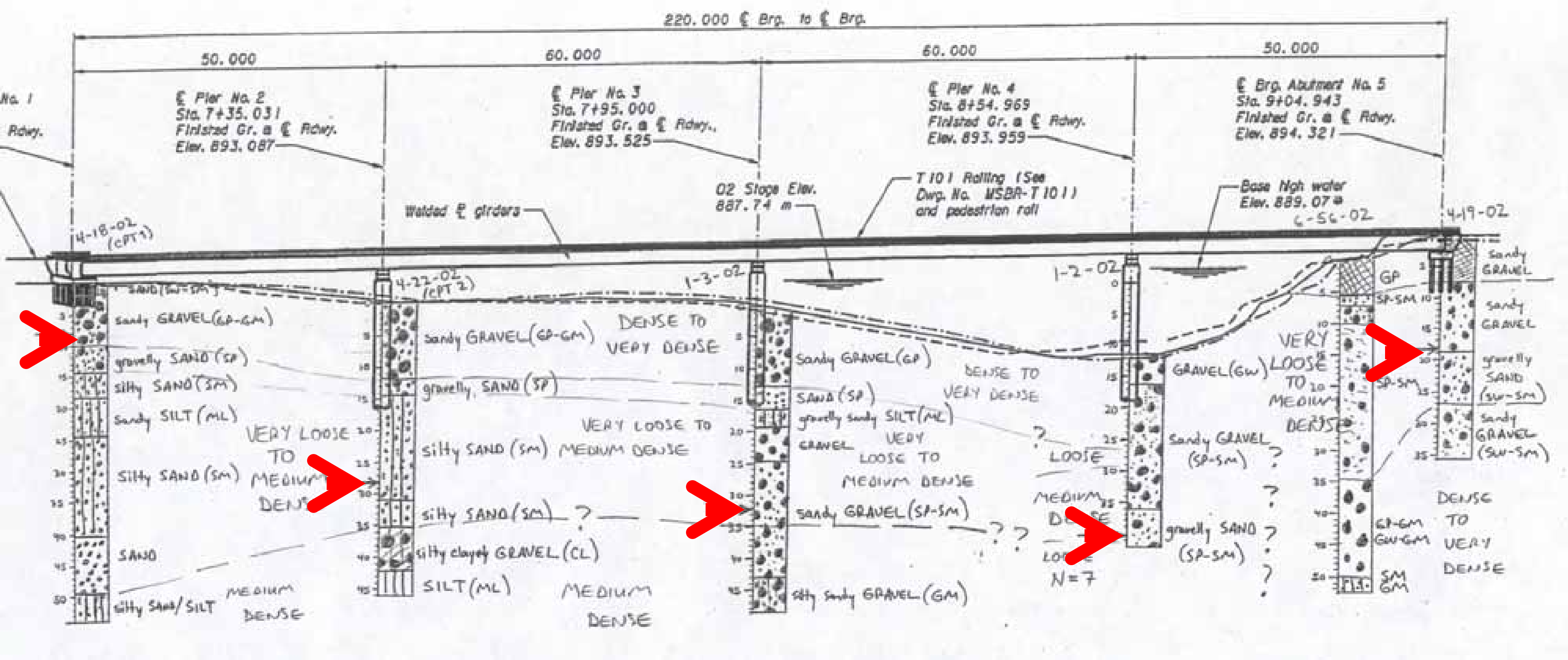
Design Recommendations

- ~~Change alignment and/or bridge layout~~
- ~~Mitigate scour~~
- Perform ground improvement around <u>***each***</u> of the foundation elements
- 508 mm (20”) pipe piles at abutments
- Build some really big drilled shafts
- Use contractor having experience installing large diameter drilled shafts below a water surface
- $ Increase cost estimate $

Design Recommendations

	Pier No. 2	**Pier No. 3**	**Pier No. 4**
Diameter, m (ft)	3.05 (10)	3.05 (10)	3.51 (11.5)
Total Length, m (ft)	30.7 (100)	35.5 (116)	43.0 (141)
Length Below Scour El., m (ft)	22.4 (73)	22.5 (75)	22.5 (75)

Design Recommendations



The Bids (Awarded in 2007)

BID TAB COSTS - SLETTEN CONSRUCTION

	CONCRETE CLASS DD			DRILLED SHAFT CONCRETE			REINFORCING STEEL			SEISMIC STEEL			3.585 m CASING			3.510 m DRILLED SHAFT			
PIER NO.	QTY	UNIT PRICE	COST	QTY	UNIT PRICE	COST	QTY	UNIT PRICE	COST	QTY	UNIT PRICE	COST	QTY	UNIT PRICE	COST	QTY	UNIT PRICE	COST	TOTAL/ PIER
2	71.8	$450	$32,310	319.5	$400	$127,800	5321	$3	$15,963	17150	$3	$51,450	7.2	$7,500	$54,000	31.1	$13,000	$404,300	$685,823
3	67.1	$450	$30,195	346.1	$400	$138,440	5281	$3	$15,843	18534	$3	$55,602	12	$7,500	$90,000	31.4	$13,000	$408,200	$738,280
4	67.1	$450	$30,195	414	$400	$165,600	5281	$3	$15,843	21903	$3	$65,709	19.5	$7,500	$146,250	28.1	$13,000	$365,300	$788,897
																		TOTAL COST OF DRILLED SHAFTS	$2,213,000
																		AVG COST OF DRILLED SHAFTS/m	$24,426

BID TAB COSTS - ENGINEER'S ESTIMATE

	CONCRETE CLASS DD			DRILLED SHAFT CONCRETE			REINFORCING STEEL			SEISMIC STEEL			3.585 m CASING			3.510 m DRILLED SHAFT			
PIER NO.	QTY	UNIT PRICE	COST	QTY	UNIT PRICE	COST	QTY	UNIT PRICE	COST	QTY	UNIT PRICE	COST	QTY	UNIT PRICE	COST	QTY	UNIT PRICE	COST	TOTAL/ PIER
2	71.8	$700	$50,260	319.5	$650	$207,675	5321	$3.25	$17,293	17150	$3	$51,450	7.2	$4,500	$32,400	31.1	$6,000	$186,600	$545,678
3	67.1	$700	$46,970	346.1	$650	$224,965	5281	$3.25	$17,163	18534	$3	$55,602	12	$4,500	$54,000	31.4	$6,000	$188,400	$587,100
4	67.1	$700	$46,970	414	$650	$269,100	5281	$3.25	$17,163	21903	$3	$65,709	19.5	$4,500	$87,750	28.1	$6,000	$168,600	$655,292
																		TOTAL COST OF DRILLED SHAFTS	$1,788,071
																		AVG COST OF DRILLED SHAFTS/m	$19,736

BID TAB COSTS - COP CONSTRUCTION

	CONCRETE CLASS DD			DRILLED SHAFT CONCRETE			REINFORCING STEEL			SEISMIC STEEL			3.585 m CASING			3.510 m DRILLED SHAFT			
PIER NO.	QTY	UNIT PRICE	COST	QTY	UNIT PRICE	COST	QTY	UNIT PRICE	COST	QTY	UNIT PRICE	COST	QTY	UNIT PRICE	COST	QTY	UNIT PRICE	COST	TOTAL/ PIER
2	71.8	$900	$64,620	319.5	$420	$134,190	5321	$2	$10,642	17150	$1.9	$32,585	7.2	$5,800	$41,760	31.1	$7,900	$245,690	$529,487
3	67.1	$900	$60,390	346.1	$420	$145,362	5281	$2	$10,562	18534	$1.9	$35,215	12	$5,800	$69,600	31.4	$7,900	$248,060	$569,189
4	67.1	$900	$60,390	414	$420	$173,880	5281	$2	$10,562	21903	$1.9	$41,616	19.5	$5,800	$113,100	28.1	$7,900	$221,990	$621,538
																		TOTAL COST OF DRILLED SHAFTS	$1,720,213
																		AVG COST OF DRILLED SHAFTS/m	$18,987

BID TAB COSTS - MORGEN & OSWOOD - BID WITHDRAWN DUE TO ERROR

	CONCRETE CLASS DD			DRILLED SHAFT CONCRETE			REINFORCING STEEL			SEISMIC STEEL			3.585 m CASING			3.510 m DRILLED SHAFT			
PIER NO.	QTY	UNIT PRICE	COST	QTY	UNIT PRICE	COST	QTY	UNIT PRICE	COST	QTY	UNIT PRICE	COST	QTY	UNIT PRICE	COST	QTY	UNIT PRICE	COST	TOTAL/ PIER
2	71.8	$732	$52,558	319.5	$195	$62,303	5321	$4.4	$23,412	17150	$2.25	$38,588	7.2	$5,500	$39,600	31.1	$8,200	$255,020	$471,480
3	67.1	$732	$49,117	346.1	$195	$67,490	5281	$4.4	$23,236	18534	$2.25	$41,702	12	$5,500	$66,000	31.4	$8,200	$257,480	$505,025
4	67.1	$732	$49,117	414	$195	$80,730	5281	$4.4	$23,236	21903	$2.25	$49,282	19.5	$5,500	$107,250	28.1	$8,200	$230,420	$540,035
																		TOTAL COST OF DRILLED SHAFTS	$1,516,540
																		AVG COST OF DRILLED SHAFTS/m	$16,739

Bid Results

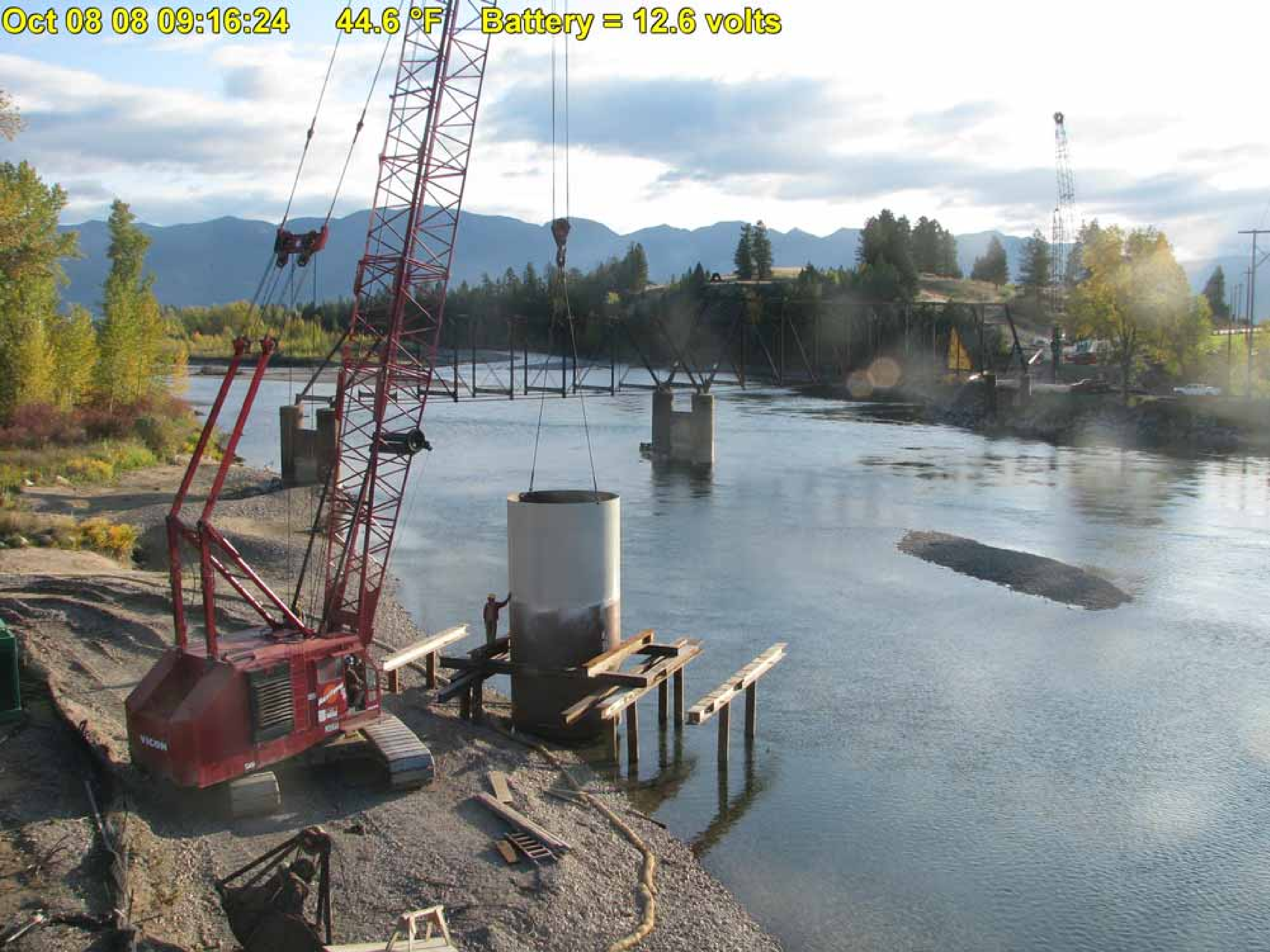
ASING		3.510 m DRILLED SHAFT			
T CE	COST	QTY	UNIT PRICE	COST	TOTAL/ PIER
00	$54,000	31.1	$13,000	$404,300	$685,823
00	$90,000	31.4	$13,000	$408,200	$738,280
00	$146,250	28.1	$13,000	$365,300	$788,897
	TOTAL COST OF DRILLED SHAFTS				$2,213,000
	AVG COST OF DRILLED SHAFTS/m				$24,426

ASING		3.510 m DRILLED SHAFT			
T CE	COST	QTY	UNIT PRICE	COST	TOTAL/ PIER
00	$32,400	31.1	$6,000	$186,600	$545,678
00	$54,000	31.4	$6,000	$188,400	$587,100
00	$87,750	28.1	$6,000	$168,600	$655,292
	TOTAL COST OF DRILLED SHAFTS				$1,788,071
	AVG COST OF DRILLED SHAFTS/m				$19,736

ASING		3.510 m DRILLED SHAFT			
T CE	COST	QTY	UNIT PRICE	COST	TOTAL/ PIER
00	$41,760	31.1	$7,900	$245,690	$529,487
00	$69,600	31.4	$7,900	$248,060	$569,189
00	$113,100	28.1	$7,900	$221,990	$621,538
	TOTAL COST OF DRILLED SHAFTS				$1,720,213
	AVG COST OF DRILLED SHAFTS/m				$18,987

ASING		3.510 m DRILLED SHAFT			
T CE	COST	QTY	UNIT PRICE	COST	TOTAL/ PIER
00	$39,600	31.1	$8,200	$255,020	$471,480
00	$66,000	31.4	$8,200	$257,480	$505,025
00	$107,250	28.1	$8,200	$230,420	$540,035
	TOTAL COST OF DRILLED SHAFTS				$1,516,540
	AVG COST OF DRILLED SHAFTS/m				$16,739

Construction


Oct 08 08 09:16:24 44.6 °F Battery = 12.6 volts


Oct 08 08 10:34:25
50.0 °F
Battery = 13.8 volts
VICON


Oct 16 08 09:27:29 32.0 °F Battery = 12.3 volts
VICON


Oct 09 08 10:05:14 33.8 °F Battery = 13.0 volts


Oct 27 08 09:53:22 35.6 °F Battery = 12.7 volts
VICON

Oct 09 08 11:40:47 42.8 °F Battery = 13.8 volts
VICON


Nov 05 08 15:57:46 35.6 °F Battery = 12.0 volts


Nov 06 08 08:49:17 30.2 °F Battery = 12.2 volts


Jan 29 09 10:58:07 24.8 °F Battery = 12.6 volts


Jan 30 09 13:01:03   55.4 °F   Battery = 14.0 volts


Feb 06 09 10:02:44 30.2 °F Battery = 13.0 volts
Genie S-65

Questions?